Routledge
Taylor & Francis Group

Economic Research-Ekonomska Istraživanja

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/rero20

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To cite this article: Bo Gao, Ilhan Ozturk & Sana Ullah (2023) A new framework to the green economy: asymmetric role of public-private partnership investment on environment in selected Asian economies, Economic Research-Ekonomska Istraživanja, 36:1, 1960-1971, DOI: 10.1080/1331677X.2022.2094441

To link to this article: https://doi.org/10.1080/1331677X.2022.2094441

Published online: 11 Jul 2022.

ECONOMIC RESEARCH-EKONOMSKA ISTRAŽIVANJA
2023, VOL. 36, NO. 1, 1960–1971
https://doi.org/10.1080/1331677X.2022.2094441

A new framework to the green economy: asymmetric role of public-private partnership investment on environment in selected Asian economies

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ABSTRACT
This study empirically examines the asymmetric relationship between public-private partnerships investment in the energy (PPPIE) sector and CO2 emissions for selected Asia economies from 1990 to 2019. For estimation, we used the nonlinear autoregressive distributed lag modelling (NARDL) econometric approach. The findings reveal that a positive change in PPPIE hinders environmental quality by increasing CO2 emissions in Indonesia and Russia in long run. On the contrary, a positive change in PPPIE has a negative influence on CO2 emissions in China and Turkey in long run. The negative shock of PPPIE mitigates the CO2 emissions in long-run in Russia, Indonesia, and Turkey. However, a positive change in PPPIE improves environmental quality by decreasing CO2 emissions in India, Indonesia, and Turkey in the short run. Although a negative change in PPPIE has negative effects on CO2 emissions in only Indonesia, while it has positive effects in India, Russia, and Turkey in the short run. Therefore, the government should encourage public-private partnerships investment in the renewable energy sector in the selected Asian economies by encouraging environmental quality.

ARTICLE HISTORY
Received 26 September 2021
Accepted 21 June 2022

KEYWORDS
Public-private partnership; CO2; NARDL

JEL CODES
R3; Q4; Q5; CO2

1. Introduction

The fact is developing and developed economies are facing some biggest challenges in the form of environmental pollution and climate change in the way to attain sustainable economic growth (Liu et al., 2022). Environmental deprivation caused serious pressure on biodiversity. Environmental degradation results in decreased production of world food and increased sea levels. It also results in increased mortality and morbidity (Dvorak et al., 2018; Usman et al., 2022). Consequently, in the absence of precautionary measures, degradation of the environment is a severe risk to the universal

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economic system. Greenhouse gases, specifically carbon emissions, are the major contributor to the degrading environment (Davidson, 2019; Zhao et al., 2021; Skare et al., 2021). Carbon emissions account for approximately 70 percent of atmospheric meditations (Mushta et al., 2020; Li et al., 2022b).

Experts consider that decrease in pollution emissions should be an important part of the compressed policies especially for defending the environment in the 21st century. A bulk of research works show a number of determinants such as industrial activities, transport, and usage of fossil fuels, population size, economic growth, and climatic conditions that determine pollution emissions (Yazdi & Dariani, 2019; Ullah et al., 2020; Lei et al., 2022). Numerous other determinants also play a significant role in alleviating environmental problems and public-private partnership investment is among them (Shan et al., 2018; Wei & Ullah, 2022). Public-private partnership investment is demonstrated as long-term agreements between private and public institutions for confirming the provision of essential public goods and services to residents.

The energy sector has the largest share in greenhouse gas and CO2 emissions (Mofijur et al., 2019; Li et al., 2022a; Qin et al., 2022). Construction and transport are the other segments that harmfully influence the environment. Hence, Zhao et al. (2018) propose that participation of the private sector in construction and transportation can importantly diminish the amount of pollution in China. Energy sector decentralization in the form of public-private investment can increase clean energy development. As Goldthau (2014) suggests that effective utilization of energy, cost savings, increased capacity, and reforms make public-private investment an efficient policy strategy for dealing with environmental changes. Additionally, public-private investment is assumed as an efficient way to tackle the problem of pollution emissions (Chen et al., 2022; Li & Ullah, 2022).

So far, the nexus between PPPIE and environmental pollution is an ignored area. But few studies are available addressing the issue of PPPIE and pollution emissions, and most of them are based on time-series analysis. For instance, Shahbaz et al. (2020) investigated the impact of PPPIE on pollution emissions in China by employing the bootstrap ARDL co-integration method. The findings show that the association between PPPIE and pollution emissions is significant and negative in China. This indicates that PPPIE in China is significantly contributing to environmental quality. Likewise, Álvarez-Herránz et al. (2017a) examined the impact of research and development progress in the energy sector on pollution emissions in 28 OECD economies by employing the environmental Kuznets curve (EKC) approach. The results revealed that energy innovation has negatively affected pollution emissions and consequently enhances the quality of the environment.

Furthermore, Álvarez-Herránz et al. (2017b) also tested the hypothesis of EKC for green finance-CO2 nexus. The results reveal that an upsurge in green finance enhances environmental quality by reducing carbon emissions. Moreover, Ganda (2018) unveiled the determinants of carbon emissions in advanced countries by employing the GMM. The study found that investment in the renewable energy sector improves the efficiency of energy and upgrades the environment by decreasing pollution emissions. By employing bootstrapped ARDL co-integration approach, Shahbaz et al. (2019) explored the components of pollution emissions for the French nation. To measure the public energy investment variable, research and development (R&D) is employed as a proxy variable. The results showed that PPPIE leads to familiarizing efficient energy green technology which in turn improves quality of environment by reducing pollution emissions. The results also reported the unidirectional causality link between public investment and pollution emissions.

Later on, Waqih et al. (2019) examined the relationship between private investment and pollution emissions in the SAARC region. The study employed FMOLS and panel ARDL techniques. Findings reveal that a U-shaped inverted association exists between private investment and carbon emissions. Additionally, Balsalobre-Lorente et al. (2019) scrutinized the EKC hypothesis for OECD economies. Their findings indicate the presence of the EKC hypothesis. The outcomes revealed that public sector clean energy investment is significantly positively linked with environmental quality. Ganda (2018) investigated the influence of green technology investment on the degradation of environment by using data for OECD economies. The study used the GMM approach and stated that green investment lower pollution emissions to upsurge the quality of the environment. A similar finding is also described by Wei et al. (2022) for emerging Asian economies. They noted that environmental entrepreneurship can help in environmental quality by promoting green economic growth.

The empirical literature is very inadequate to justify the nexus between PPPIE and pollution emissions. The significance of renewable energy for the sustainability of the environment and energy demand is well recognized but, the role of public-private partnership investment for the environmental future and sustained energy is negligible in academic literature. No study has explored the role of public-private partnership investment in the energy sector toward pollution emissions in the existing literature of energy in the case of asymmetric analysis. In doing so, this study suggests a PPPIE sector as a new factor of pollution emissions. This study has incorporated PPPIE sector as a new factor in carbon emissions production function. Furthermore, the study applied NARDL for scrutinizing the co-integration between pollution emissions and its determinants. This study examines the asymmetric long and short-run impacts of PPPIE on CO2 emissions in Asian selected economies. The rest of the study describes the model and method, empirical results, and conclusion with implications. The findings of this study support policymakers in developing such implications for public-private partnership investment that recover the environmental performance. The findings of the study will also provide strategies to the environmental safety specialists regarding the improvement of environmental sustainability.

2. Theoretical framework, methodology, and data

Theoretically, PPPIE is associated with sustainable growth due to its importance in fulfilling the unparalleled energy demand. Thus, PPPIE is considered a policy tool to control environmental degradation. However, analysis reveals that public-private partnership investment in the energy sector enhances CO2 emissions, revealing that public-private partnership investment deteriorates the environmental quality in the long run (Raza et al., 2021). Thus, we made an effort to confirm whether the positive association between PPPIE and CO2 emissions exists in the case of Asian economies or not. The outcomes of various literature studies reveal that PPPIE has positive (Shahbaz et al., 2020, Adebayo & Akinsola, 2021, Kirikkaleli & Adebayo, 2021), negative (Anwar et al., 2021), and insignificant (Raza et al., 2021) impacts on CO2 emissions. Based on literature findings, we argue that PPPIE impact on CO2 emissions could be asymmetric. Based on such a theoretical framework, we used the following forms of the CO2 emissions model:

$$CO_{2,t} = \omega_0 + \varphi_1 PPPIE_t + \varphi_2 GDP_t + \varphi_3 FDI_t + \varphi_4 Technology_t + \varepsilon_t \quad (1)$$

Here, $CO_{2,t}$ is carbon emissions in a time period t, $PPPIE_i$ is the public-private partnership's investment in energy sector. Where GDP_t is the GDP per capita, FDIt is the FDI inflows, and $Technology_t$ is the technology innovation are used as control variable in the model. If PPPIE improves environmental quality in the long-term, an estimate of $\varphi_1$should be negative in Equation (1). The coefficient of Equation (1) is noted as long-term estimates. To judge the short-run effects of PPPIE, we express Equation (1) in an error-correction framework as:

$$\begin{aligned}\Delta CO_{2,t} = {} & \omega_0 + \sum_{k=1}^{n} \beta_{1k} \Delta CO_{2,t-k} + \sum_{k=0}^{n} \beta_{2k} \Delta PPPIE_{t-k} + \sum_{k=0}^{n} \beta_{3k} \Delta GDP_{t-k} \\ & + \sum_{k=1}^{n} \beta_{4k} \Delta FDI_{t-k} + \sum_{k=0}^{n} \beta_{5k} \Delta Technology_{t-k} + \omega_1 CO_{2,t-1} \\ & + \omega_2 PPPIE_{t-1} + \omega_3 GDP_{t-1} + \omega_4 FDI_{t-1} + \omega_5 Technology_{t-1} + \varepsilon_t \quad (2)\end{aligned}$$

where 'first-differenced' variables are described as short-run effects and ω2-ω5 coefficients are reflected as the long-run effects of concern variables on CO2 emissions. Though, for the validity of long-run effects, Pesaran et al. (2001) suggest two robust tests; name as the first one is F test and the other is t-test. Both tests in this context have their own new tabulated critical values that offer by Pesaran et al. (2001). There are two key edges of this approach is that there is no basic requirement of unit root testing because most macroeconomic variables are a mixture of I(1) and I(0). Another edge is that both long-and long-run impacts are assessed in one step. So, we do a modification for Equation (2), following Shin et al. (2014) method to disintegrate (PPPIE) into two new partial sum variables where one signifies an increase in PPPIE and the other one decrease in PPPIE.

$$PPPIE^{+}_{t} = \sum_{n=1}^{t} \Delta PPPIE^{+}_{t} = \sum_{n=1}^{t} \max\left(PPPIE^{+}_{t},\ 0\right) \quad (3a)$$

$$PPPIE^{-}_{t} = \sum_{n=1}^{t} \Delta PPPIE^{-}_{t} = \sum_{n=1}^{t} \min\left(\Delta PPPIE^{-}_{t},\ 0\right) \quad (3b)$$

Here, the $PPPIE^{+}{}_{t}$ is the partial sum of positive changes and the $PPPIE^{-}{}_{t}$ is the partial sum of negative changes. In the next stage, we replace the two partial sum variables into Equation (3) and attain the following new models:

$$\begin{aligned}\Delta CO_{2,t} = \ & \omega_0 + \sum_{k=1}^{n}\beta_{1k}\Delta CO_{2,t-k} + \sum_{k=0}^{n}\beta_{2k}\Delta PPPIE^{+}{}_{t-k} + \sum_{k=0}^{n}\delta_{3k}\Delta PPPIE^{-}{}_{t-k} \\ & + \sum_{k=0}^{n}\beta_{4k}GDP_{t-k} + \sum_{k=0}^{n}\delta_{5k}FDI_{t-k} + \sum_{k=0}^{n}\beta_{6k}Technology_{t-k} + \omega_1 CO_{2,t-1} \\ & + \omega_2 PPPIE^{+}{}_{t-1} + \omega_3 PPPIE^{-}{}_{t-1} + \omega_4 GDP_{t-1} + \omega_5 FDI_{t-1} \\ & + \omega_6 Technology_{t-1} + \varepsilon_t\end{aligned} \tag{4}$$

Since creating the partial sum variables presents asymmetric adjustment of the PPPIE, models like Equation (4) are known as asymmetric or nonlinear ARDL models while the basic model Equation (2) is a symmetric or linear ARDL model. While linear and nonlinear models have the same diagnostic tests and estimation methods (Shin et al., 2014). After estimating the short and long coefficients, a few additional asymmetry hypotheses can be tested. First, if $\Delta PPPIE^{+}{}_{t-k}$ takes a different lag order than $\Delta PPPIE^{-}{}_{t-k}$, that is one indication of short-run asymmetry. Second, the existence of short-run asymmetric impacts can be established if the Wald test nullified the conditions as, $\sum_{k=0}^{n}\beta_{2k} = \sum_{k=0}^{n}\delta_{3k}$. Finally, if the Wald test nullified the conditions as $-\omega_{2/\omega_1} = -\omega_{3/\omega_1}$, long-run asymmetric effects of PPPIE on the CO2 emissions will be established. For some other econometric applications of non-linear methods see Ullah et al. (2020), Usman et al. (2020), and Ullah et al. (2021) have used non-linear diagnostic for CO2 emissions model by using different concern variables.

We use annual data for the period of 1990–2019 for selected high pollutant Asia economies, i.e., China, India, Russia, Indonesia, and Turkey. These Asian selected countries were chosen on the basis of data availability. The data on CO2 emissions (measured in kilo tons), PPPIE (measured in current US$), GDP per capita (constant 2010 US$), FDI (measured as net inflows (% of GDP), Technology innovation (measured as patents applications) is attained from World Development Indicators given by World Bank. The dependent variable is CO2 emissions whilst the focused variable is PPPIE and regressors are GDP, FDI, and Patent. We converted all variables into a logarithm except one FDI. The details of data and variables description are given in Table 1:

3. Results and discussions

Before performing regression analysis, it is vital to confirm the unit root properties of the data. For that purpose, we have applied two unit-root tests, Phillips-Perron (PP) and Augmented Dickey-Fuller (ADF). The results of these tests are reported in table 2, findings of both tests infer that a few variables are stationary at level, i.e., I(0), and a few of them are stationary at the first difference, i.e., I(1). Hence, the NARDL methodology is employed for empirical analysis in this study.

Table 1. Variables description.

Variables	Symbol	Definition	Data source
CO_2 emissions	CO_2	CO_2 emissions (kt)	https://databank.worldbank.org/source/world-development-indicators
Public-private partnerships	PPP	Public-private investment in energy sector (current US$)	
GDP per capita	GDP	GDP per capita (constant 2010 US$)	
Technology innovation	Technology	Patent applications, residents	
Foreign direct investment	FDI	Foreign direct investment, net inflows (% of GDP)	

Source: World Bank.

Table 2. Unit root tests.

		ADF			PP		
		Level	First-difference (FD)	Decision	Level	First-difference (FD)	Decision
China	CO_2	−1.112	−4.947***	FD	−1.121	−4.946***	FD
	PPP	−1.243	−4.983***	FD	−1.279	−4.967***	FD
	GDP	−3.762***		Level	−3.742***		Level
	Technology	−0.281	−3.125***	FD	−0.326	−3.212***	FD
	FDI	−1.626	−4.680***	FD	−1.631	−4.733***	FD
Russia	CO_2	−12.29***		Level	−10.01***		Level
	PPP	−2.517	−7.730***	FD	−2.486	−8.059***	FD
	GDP	−2.421	−7.772***	FD	−2.275	−8.177***	FD
	Technology	−0.486	−5.166***	FD	−0.616	−5.167***	FD
	FDI	−7.018***		Level	−5.899***		Level
India	CO_2	−0.791	−4.379***	FD	−0.773	−4.368***	FD
	PPP	−2.426	−4.697***	FD	−2.557	−4.661***	FD
	GDP	−4.909***		Level	−4.990***		Level
	Technology	−2.501	−5.647***	FD	−2.583*		Level
	FDI	−1.751	−4.184***	FD	−1.762	−4.152***	FD
Indonesia	CO_2	−2.056	−5.485***	FD	−2.331	−6.438**	FD
	PPP	−3.159**		Level	−3.072**		Level
	GDP	−1.848	−3.912***	FD	−0.047	−3.853***	FD
	Technology	−0.399	−9.254***	FD	−0.057	−9.695***	FD
	FDI	−2.851*		Level	−2.250	−5.034***	FD
Turkey	CO_2	−1.242	−6.939***	FD	−1.321	−5.989***	FD
	PPP	−3.017*		Level	−3.138**		Level
	GDP	−0.136	−5.428***	FD	−0.811	−5.450***	FD
	Technology	−0.213	−4.554***	FD	−0.077	−4.637***	FD
	FDI	−2.135	−4.896***	FD	−2.113	−4.906***	FD

Note:
***$p < 0.01$;. **$p < 0.05$; and *$p < 0.1$.
Source: Authors' Calculations.

The asymmetric/nonlinear ARDL findings of selected Asian economies are described in Table 3. The short-run public-private partnerships investment results reveal that positive change has a negative effect on pollution emissions in India, Indonesia, and Turkey, however, insignificant impact in China and Russia. It indicates that 1% increase in public-private partnership investment would decrease pollution emissions to 0.022% in India, 0.060% in Indonesia, and 0.011% in Turkey. The negative shock to public-private partnerships investment has positive results in India, Russia, and Turkey, and the negative shock infers a negative effect on pollution emissions in Indonesia. Correspondingly, the results show that 1% fall in public-private partnerships investment results in increased carbon emissions by 0.020% in India, 0.012% in Russia, and 0.064% in Turkey, while pollution emissions would fall by 0.178% in Indonesia in the short-run. The short-run findings for GDP reveal that 1%

Table 3. Long-and short-run estimates of PPPIE and CO2 emissions.

	China		India		Russia		Indonesia		Turkey	
Variable	Coefficient	t-Stat	Coefficient	t-Stat	Coefficient	t-Stat	Coefficient	t-Stat	Coefficient	t-Stat
Short-run										
D(PPPIE_POS)	0.020	0.627	−0.022*	1.774	0.003	0.617	−0.060*	1.906	−0.011*	1.762
D(PPPIE_POS(-1)	0.048**	2.102			−0.015	2.216	0.057**	2.472		
D(PPPIE_NEG)	−0.004	0.317	0.020*	1.671	0.012*	1.749	−0.178***	4.759	0.064***	4.353
D(PPPIE_NEG(-1)							−0.091	1.574		
D(GDP)	−2.749*	1.681	0.113	0.102	0.858***	4.102	5.303***	6.515	0.813***	4.380
D(GDP(-1)			−1.701*	1.761			1.478	1.553		
D(FDI)	0.127***	3.500	0.002	0.047	−0.001	0.167	−0.138***	3.853	0.004	0.262
D(FDI(-1)	−0.046**	2.483			0.035***	3.268				
D(Technology)	0.296***	3.118	−0.234*	1.670	0.071	1.076	0.286***	4.001	0.142***	3.141
D(Technology(-1)			−0.448**	1.994	−0.067*	1.727	0.377***	5.174		
Long-run										
PPPIE_POS	−0.040*	1.675	0.044	0.825	0.023*	1.930	0.236***	3.159	−0.018*	1.875
PPPIE_NEG	−0.006	0.307	−0.055	0.771	0.040**	2.413	0.283***	2.843	0.110***	4.031
GDP	0.113	0.348	−2.700*	1.762	0.786*	1.928	−0.972*	1.770	1.393***	4.103
FDI	0.228***	6.396	−0.097	1.164	−0.068***	3.452	0.108***	3.673	0.046*	1.899
Technology	0.381***	3.337	1.339*	1.910	−0.045	0.307	0.599***	3.629	0.243***	3.534
C	9.837***	5.410	21.29***	4.104	7.918***	3.093	17.28***	3.623	−1.531	0.504
Diagnostic										
F-test	2.010		4.175*		6.178**		1.885		4.223**	
ECM(-1)	−0.779***	3.927	−0.453***	2.734	−0.495***	3.080	−0.711**	2.375	−0.584***	4.218
LM	0.244		1.969		0.167		2.695*		1.716	
BPG	1.427		1.762		0.473		0.860		0.984	
RESET	0.011		0.468		2.026		0.700		1.985	
CUSUM	S		S		S		S		S	
CUSUM-sq	S		S		S		S		US	
Wald-SR	1.235		1.333		3.112*		4.879***		1.001	
Wald-LR	3.854**		1.235		2.987*		3.214*		4.987***	

Note:.
***$p < 0.01$;.
**$p < 0.05$; and.
*$p < 0.1$.
Source: Authors' Calculations.

increase in GDP would decrease pollution emissions in China by 2.749%, while pollution emissions would increase by 0.858% in Russia, 5.303% in Indonesia and 0.813% in Turkey. Results for foreign direct investment indicate that 1% increase in FDI would increase pollution emissions by 0.127% in India and pollution emissions would fall by 0.138% in Indonesia. In case of innovation, results demonstrate that 1% increase in innovations would increase pollution emissions to 0.296% in China, 0.286% in Indonesia, and 0.142% in Turkey, while pollution emissions decrease by 0.234% in Russia.

The long-run coefficients of public-private partnerships investment results demonstrate that positive shock has a positive effect on pollution emissions in Russia and Indonesia however, significant negative impact on pollution emissions in China and Turkey. It indicates that 1% increase in positive components of public-private partnership investment would increase pollution emissions by 0.023% in Russia and 0.236% in Indonesia. This outcome is also reliable to the study of Shahbaz et al. (2020), who noted that PPPIE has a significant and positive effect on CO2 emissions. This result is consistent with Buso and Stenger, (2018), who noted that public–private partnerships are increasing the domestic output by reducing the environmental quality. The possible reason is that public-private partnership is more investment in fossil fuel energy due to high economic return on investment, thus adversely affecting the environment. The reason behind the positive interconnection between public-private partnership-CO2 is that Russia and Indonesia have to achieve economic expansion without increasing the environmental quality. Finding infers that 1% increase in positive components of public-private partnership investment would fall pollution emissions by 0.040% in China and 0.018% in Turkey in the long-run. Finding also infers that PPPIE is encouraged environmental quality in China and Turkey.

Findings reported that the influence of PPPIE on CO2 emissions is positive in the long-run in Indonesia and Russia, revealing that PPPIE negatively influences environmental sustainability. The reason behind this association is that most of the public-private partnership investment projects in Indonesia and Russia are based on non-renewable energies that bring serious damage to environmental quality. Hence, PPPIE adversely influences environmental sustainability in Indonesia and Russia. Additionally, it is argued that PPPIE is not enough to enhance the sustainability of the environment without the transformation of energy sources from fossil fuels to renewable energy sources. Our findings are supported by York and Bell (2019) and Shahbaz et al. (2020). Another study done by Anwar et al. (2021) provides the same results by claiming that public-private partnership investment deteriorates environmental quality by intensifying CO2 emissions.

The negative shock of public-private partnerships investments has a positive influence on pollution emissions in Russia, Indonesia, and Turkey, except in China and India. The coefficient estimates reveal that 1% decrease in public-private partnerships investments raised pollution emissions by 0.040% in Russia, 0.236% in Indonesia, and 0.110% in Turkey, respectively. In case of GDP results demonstrate that 1% increase in GDP would increase pollution emissions by 0.786% in Russia and 1.393% in Turkey, while pollution emissions fall by 2.700% in India and 0.972% in Indonesia. The long-run findings for foreign direct investment reveal that 1% increase in FDI would decrease pollution emissions in Russia by 0.068%, while pollution emissions would increase by 0.228% in China, 0.108% in Indonesia and 0.046% in Turkey. Results for innovation indicate that 1% increase in innovation would increase pollution emissions by 0.381% in China, 1.339% in India, 0.599% in Indonesia, and 0.243% in Turkey.

The lower panel of Table 3 demonstrates the results of other diagnostic tests. The F-statistics validate the long-run association among variables in only India, Russia, and Turkey. The error correction term (ECT) is a significant negative for all selected countries with coefficients equal to −0.779, −0.453, −0.495, −0.711, and −0.584 for China, India, Russia, Indonesia, and Turkey. The speed of convergence toward the long-run equilibrium is almost 77% for each year for China, 45% for India, 49% for Russia, 71% for Indonesia, and 58% for Turkey. However, other diagnostic numbers also confirm that the nonlinear models are reliable and usable. For example, the coefficient estimates of LM test, BPG test, and Ramsey RESET test confirm the absence of autocorrelation problem (except in Indonesia) and heteroskedasticity problem, normality of residuals, and selection of correct functional form of asymmetric ARDL models. Also, both CUSUM tests confirm the stability of models except Turkey in CUSUM-sq test. The findings of Wald test reported that PPPIE shocks have a nonlinear link with pollution emissions in the mostly selected economies in long run.

4. Conclusion and implications

The study aims to scrutinize the asymmetric impact of PPPIE on CO2 emissions for selected Asian nations by utilizing the annual dataset over the period 1990–2019. To the best of our understanding, previous literature does not explore this nexus asymmetrically for Asian economies. To explore the asymmetric relationship between PPPIE and carbon emissions, the study utilized a nonlinear ARDL approach. The findings of NARDL revealed that a positive change in PPPIE has a positive significant effect on CO2 in Russia and Indonesia, while it has negative effects in China and Turkey in the long run. Furthermore, a negative change in PPPIE has a harmful effect on CO2 in Russia, Indonesia, and Turkey in long run. Moreover, a positive change in PPPIE has a negative influence on CO2 emissions in India, Indonesia, and Turkey in short run. Contrarily, a positive change in PPPIE improves the environment by deteriorating CO2 emissions whilst it has positive effects on CO2 emissions in Russia, India, and Turkey in the short run.

Based on the findings, this study proposes some relevant policy implications. The present study suggests that policymakers and authorities should encourage green investments to improve the environment. Furthermore, authorities should introduce green investments in green technology for clean energy production. This study recommends public-private partnership investment in clean energy projects. Policymakers should emphasize public-private partnership investment in other sectors like water and sanitation, ICT, and transport for environmental quality. Although our study used a recent econometric approach to explore the nexus, whereas it has certain limitations. For instance, the study only focused on a small range of Asian economies in analysis and limited time span (1990–2019). Also, due to the non-availability of data, our study only focused on five Asian countries. Upcoming empirical studies could potentially inspect the dynamic impact of public-private investments in energy on renewable energy production by utilizing the existing alternate parameter measures. Authors should also conduct a similar analysis for other nations for sound policies. Future studies must be focused on high pollutant economies.

This work was funded by

National Natural Science Foundation of China, 2020, Coupling Mechanism and Simulation regulation of Ecological environment Protection and Industrial Structure Optimization in water source region of the middle route of South-to-North Water Transfer, Project No.: 42077449, project leader: Fu Jingbao.

National Natural Science Foundation of China, 2017, U1704124, Principal investigator: Fu Jingbao. Mechanism and Simulation of Multi-body Cooperative governance of ecological environment in water source region of the middle route of South-to-North Water Transfer.

Humanities and Social Science Project of Ministry of Education: Coupling coordination mechanism and Dynamic regulation of water Ecological Environment and economy in water source region of the Middle Route of South-to-North Water Transfer Project, Project Number: 19YJC630075, principal: Li Hongyan

Science and Technology Innovation Team of Education Department of Henan Province: Public Resources and Environmental Governance, Project number: 19IRTSHN015, project leader: Li Hongyan.

2018 National Natural Science Foundation of China (NSFC): Study on cooperative treatment of agricultural non-point source pollution in water source of the Middle Route of South-to-North Water Transfer Project, Project Number: 71804042, principal: Chu Yu.

Philosophy and Social Science Planning Project of Henan Province: Research on High-quality Development of Ecological Environment and Economic Coupling in Henan Province, Project No.:2020BJJ021, Project leader: Chu Yu.

Disclosure statement

No conflict of interest has been declared by the authors.

References

Adebayo, T. S., & Akinsola, G. D. (2021). Investigating the causal linkage among economic growth, energy consumption and CO2 emissions in Thailand: An application of the wavelet coherence approach. *International Journal of Renewable Energy Development*, *10*(1), 17–26. https://doi.org/10.14710/ijred.2021.32233

Álvarez-Herránz, A., Balsalobre, D., Cantos, J. M., & Shahbaz, M. (2017a). Energy innovations GHG emissions nexus: Fresh empirical evidence from OECD countries. *Energy Policy*, *101*, 90–100. https://doi.org/10.1016/j.enpol.2016.11.030

Álvarez-Herránz, A., Balsalobre-Lorente, D., Shahbaz, M., & Cantos, J. M. (2017b). Energy innovation and renewable energy consumption in the correction of air pollution levels. *Energy Policy*, *105*, 386–397. https://doi.org/10.1016/j.enpol.2017.03.009

Anwar, A., Sharif, A., Fatima, S., Ahmad, P., Sinha, A., Khan, S. A. R., & Jermsittiparsert, K. (2021). The asymmetric effect of public private partnership investment on transport CO2 emission in China: Evidence from quantile ARDL approach. *Journal of Cleaner Production*, *288*, 125282. https://doi.org/10.1016/j.jclepro.2020.125282

Balsalobre-Lorente, D., Shahbaz, M., Jabbour, C. J. C., & Driha, O. M. (2019). The role of energy innovation and corruption in carbon emissions: Evidence based on the EKC hypothesis. In: *Energy and Environmental Strategies in the Era of Globalization* (pp. 271–304). Springer.

Buso, M., & Stenger, A. (2018). Public-private partnerships as a policy response to climate change. *Energy Policy*, *119*, 487–494. https://doi.org/10.1016/j.enpol.2018.04.063

Chen, J., Rojniruttikul, N., Kun, L. Y., & Ullah, S. (2022). Management of green economic infrastructure and environmental sustainability in one belt and road enitiative economies. *Environmental Science and Pollution Research International*, *29*(24), 36326–36336.

Davidson, D. J. (2019). Exnovating for a renewable energy transition. *Nature Energy*, *4*(4), 254–256. https://doi.org/10.1038/s41560-019-0369-3

Dvorak, A. C., Solo-Gabriele, H. M., Galletti, A., Benzecry, B., Malone, H., Boguszewski, V., & Bird, J. (2018). Possible impacts of sea level rise on disease transmission and potential adaptation strategies, a review. *Journal of Environmental Management*, *217*, 951–968. https://doi.org/10.1016/j.jenvman.2018.03.102

Ganda, F. (2018). The influence of green energy investments on environmental quality in OECD countries. *Environmental Quality Management*, *28*(2), 17–29. https://doi.org/10.1002/tqem.21595

Goldthau, A. (2014). Rethinking the governance of energy infrastructure: Scale, decentralization and polycentrism. *Energy Research & Social Science*, *1*, 134–140. https://doi.org/10.1016/j.erss.2014.02.009
Kirikkaleli, D., & Adebayo, T. S. (2021). Do public-private partnerships in energy and renewable energy consumption matter for consumption-based carbon dioxide emissions in India? *Environmental Science and Pollution Research International*, *28*(23), 30139–30152.
Lei, W., Xie, Y., Hafeez, M., & Ullah, S. (2022). Assessing the dynamic linkage between energy efficiency, renewable energy consumption, and CO2 emissions in China. *Environmental Science and Pollution Research International*, *29*(13), 19540–19552. https://doi.org/10.1007/s11356-021-17145-7
Li, W., & Ullah, S. (2022). Research and development intensity and its influence on renewable energy consumption: Evidence from selected Asian economies. *Environmental Science and Pollution Research*, https://doi.org/10.1007/s11356-022-19650-9
Li, X., Ozturk, I., Majeed, M. T., Hafeez, M., & Ullah, S. (2022a). Considering the asymmetric effect of financial deepening on environmental quality in BRICS economies: Policy options for the green economy. *Journal of Cleaner Production*, *331*, 129909. https://doi.org/10.1016/j.jclepro.2021.129909
Li, X., Ozturk, I., Ullah, S., Andlib, Z., & Hafeez, M. (2022b). Can top-pollutant economies shift some burden through insurance sector development for sustainable development? *Economic Analysis and Policy*, *74*, 326–336. https://doi.org/10.1016/j.eap.2022.02.006
Liu, D., Zhang, Y., Hafeez, M., & Ullah, S. (2022). Financial inclusion and its influence on economic-environmental performance: demand and supply perspectives. *Environmental Science and Pollution Research*. In press, https://doi.org/10.1007/s11356-022-18856-1
Mofijur, M., Mahlia, T., Silitonga, A., Ong, H., Silakhori, M., Hasan, M., Putra, N., & Rahman, S. M. (2019). Phase change materials (PCM) for solar energy usages and storage: An overview. *Energies*, *12*(16), 3167. https://doi.org/10.3390/en12163167
Mushta, A., Chen, Z., Ud Din, N., Ahmad, B., & Zhang, X. (2020). Income inequality, innovation and carbon emission: Perspectives on sustainable growth. *Economic Research-Ekonomska Istraživanja*, *33*(1), 769–787. https://doi.org/10.1080/1331677X.2020.1734855
Pesaran, M. H., Shin, Y., & Smith, R. J. (2001). Bounds testing approaches to the analysis of level relationships. *Journal of Applied Econometrics*, *16*(3), 289–326. https://doi.org/10.1002/jae.616
Raza, S. A., Shah, S. H., & Yousufi, S. Q. (2021). The impact of public-private partnerships Investment in Energy on carbon emissions: Evidence from nonparametric causality-in-quantiles. *Environmental Science and Pollution Research International*, *28*(18), 23182–23192.
Qin, Y., Xu, Z., Wang, X., & Škare, M. (2022). Green energy adoption and its determinants: A bibliometric analysis. *Renewable and Sustainable Energy Reviews*, *153*, 111780. https://doi.org/10.1016/j.rser.2021.111780
Shahbaz, M., Raghutla, C., Song, M., Zameer, H., & Jiao, Z. (2020). Public-private partnerships investment in energy as new determinant of CO2 emissions:T role of technological innovations in China. *Energy Economics*, *86*, 104664. https://doi.org/10.1016/j.eneco.2020.104664
Shahbaz, M., Balsalobre-Lorente, D., & Sinha, A. (2019). Foreign direct investment–CO2 emissions nexus in Middle East and North African countries: Importance of biomass energy consumption. *Journal of Cleaner Production*, *217*, 603–614. https://doi.org/10.1016/j.jclepro.2019.01.282
Shan, Y., Guan, D., Zheng, H., Ou, J., Li, Y., Meng, J., Mi, Z., Liu, Z., & Zhang, Q. (2018). China CO 2 emission accounts 1997–2015. *Scientific Data*, *5*, 170201. https://doi.org/10.1038/sdata.2017.201
Shin, Y., Yu, B., & Greenwood-Nimmo, M. (2014). Modelling asymmetric cointegration and dynamic multipliers in a nonlinear ARDL framework. In *Festschrift in honor of Peter Schmidt* (pp. 281–314). Springer.
Skare, M., Streimikiene, D., & Skare, D. (2021). Measuring carbon emission sensitivity to economic shocks: a panel structural vector autoregression 1870–2016. *Environmental Science*

and Pollution Research International, *28*(32), 44505–44521. https://doi.org/10.1007/s11356-021-13636-9

Ullah, S., Ozturk, I., & Sohail, S. (2021). The asymmetric effects of fiscal and monetary policy instruments on Pakistan's environmental pollution. *Environmental Science and Pollution Research International*, *28*(6), 7450–7461.

Ullah, S., Ozturk, I., Usman, A., Majeed, M. T., & Akhtar, P. (2020). On the asymmetric effects of premature deindustrialization on CO2 emissions: Evidence from Pakistan. *Environmental Science and Pollution Research International*, *27*(12), 13692–13702.

Usman, A., Ozturk, I., Naqvi, S. M. M. A., Ullah, S., & Javed, M. I. (2022). Revealing the nexus between nuclear energy and ecological footprint in STIRPAT model of advanced economies: Fresh evidence from novel CS-ARDL model. *Progress in Nuclear Energy*, *148*, 104220. https://doi.org/10.1016/j.pnucene.2022.104220

Usman, A., Ullah, S., Ozturk, I., Chishti, M. Z., & Zafar, S. M. (2020). Analysis of asymmetries in the nexus among clean energy and environmental quality in Pakistan. *Environmental Science and Pollution Research International*, *27*(17), 20736–20747.

Waqih, M. A. U., Bhutto, N. A., Ghumro, N. H., Kumar, S., & Salam, M. A. (2019). Rising environmental degradation and impact of foreign direct investment: An empirical evidence from SAARC region. *Journal of Environmental Management*, *243*, 472–480. https://doi.org/10.1016/j.jenvman.2019.05.001

Wei, K., Ren, H., Ullah, S., & Bozkurt, C. (2022). Does environmental entrepreneurship play a role in sustainable green development? Evidence from emerging Asian economies. *Economic Research-Ekonomska Istraživanja*, 1–13. https://doi.org/10.1080/1331677X.2022.2067887

Wei, L., & Ullah, S. (2022). International tourism, digital infrastructure, and CO2 emissions: Fresh evidence from panel quantile regression approach. *Environmental Science and Pollution Research*, *29*(24), 36273–36280. https://doi.org/10.1007/s11356-021-18138-2

Yazdi, S. K., & Dariani, A. G. (2019). CO2 emissions, urbanisation and economic growth: Evidence from Asian countries. *Economic Research-Ekonomska Istraživanja*, *32*(1), 510–530. https://doi.org/10.1080/1331677X.2018.1556107

York, R., & Bell, S. E. (2019). Energy transitions or additions?: Why a transition from fossil fuels requires more than the growth of renewable energy. *Energy Research & Social Science*, *51*, 40–43. https://doi.org/10.1016/j.erss.2019.01.008

Zhao, Z. J., Su, G., & Li, D. (2018). The rise of public-private partnerships in China. *Journal of Chinese Governance*, *3*(2), 158–176. https://doi.org/10.1080/23812346.2018.1457297

Zhao, W., Hafeez, M., Maqbool, A., Ullah, S., & Sohail, S. (2021). Analysis of income inequality and environmental pollution in BRICS using fresh asymmetric approach. *Environmental Science and Pollution Research International*, *28*(37), 51199–51209.